POLARIZATION-DEPENDENCE IN THE PERFORMANCE OF A GROUND PLANE CROSS SECTION RANGE

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The ground plane range, used successfully for antenna pattern measurements, has been proposed as a technique for radar cross section measurement. While this approach offers recognized advantages, certain features with respect to polarization behavior warrant further study. A brief analytical examination of polarization effects was made at this Laboratory in March 1962 and was accompanied by experimental studies upon our K_a-band CW radar cross section range which confirmed the analytical predictions. These results are reported here.

The basic assumption in ground plane operation is that the reflection coefficients for both polarizations approach the value (-1) as the incidence angle approaches 90 degrees (grazing incidence). The far field pattern of the transmitting antenna-groundplane combination then approaches that of an array formed by the actual transmitting antenna and its image. In simplified form, the far field pattern is approximated by the expression:

$$E = A\left[g(\theta) - g(\theta')e^{-i\psi}\right]$$

where A = constant

θ = angle between transmitting antenna symmetry axis and line of sight to target

$g(\theta)$ = amplitude pattern of actual transmitting

θ' = angle between image antenna symmetry axis and line of sight from it to target

$g(\theta')$ = amplitude pattern of image antenna

ψ = path length phase differential between actual antenna and its image

With the target sufficiently far from the transmitter and with the antenna beam symmetry axis parallel to the groundplane, the further assumption of $g(\theta) = g(\theta')$ can be made, so that the pattern is given by:

$$E = 2iA\, g(\theta) \sin\frac{\psi}{2}$$

It can be readily shown, moreover, that the controlling pattern factor is $\sin\frac{\psi}{2}$, so that peak amplitude is found at $\frac{\psi}{2} = \frac{\pi}{2}$. The resultant pattern parameters are then:

(1) Main lobe elevation angle - $\alpha = \frac{\lambda}{4\eta_a}$

(2) Half-power beamwidth - $\beta = \frac{\lambda}{4\eta_a}$

where η_a is antenna height above the plane and τ is the operating wavelength.

In actual practice, the reflection coefficient for either horizontal or vertical polarization never achieves the value (-1), and differs for the two polarizations. It exhibits its greatest sensitivity to incidence angle at the low incidence angles used in groundplane range, and the difference between the reflection coefficients for the two principal polarizations is greatest in this neighborhood. Furthermore, the frequently used assumption of reflection of the spherical wavefront at a single specular point (determined jointly by the positions of antenna, target, and groundplane) oversimplifies the reflection process and masks the effects of (1) nonuniform reradiation from the target, and (2) steep variations of local reflection coefficient with frequency and aspect angle. The true radar power return will involve these factors and must be computed by an appropriately weighted integral over the entire groundplane surface, with weighting dependent upon local incidence angle and frequency and upon the reradiation pattern from the target. Even when the latter approximates a uniform scatterer, the reflection coefficient so computed for vertical polarization of the electric vector may differ markedly from that for the specular point alone. The coefficient obtained by properly weighted integration of scattered signal from an assumed uniform scatterer will be called the effective reflection coefficient and will be used in the following discussion.

The description of the far field pattern must be formulated separately for the two polarizations. For the horizontal case it is:

$$E_H = Ag(\theta)\left[1 + r_\eta e^{-i\psi}\right]$$

while for the vertical case:

$$E_V = Ag(\theta)\left[1 + r_v e^{-i\psi}\right]$$

where r_η = effective reflection coefficient-horizontal polarization

r_v = effective reflection coefficient-vertical polarization

For radar cross-section measurement with a groundplane range, the target also has an image, so that reflection coefficient enters into the equations twice. For an isotropic scatterer the received signals for the two polarizations become:

$$E_{REC(H)} = A^2 g(\theta)^2 K\left[1 + r_\eta e^{-i\psi}\right]^2$$

$$E_{REC(V)} = A^2 g(\theta)^2 K\left[1 + r_v e^{-i\psi}\right]^2$$

where k is a constant.

Differences in the reflection coefficients which appear at grazing incidence thus cause both the signal amplitude return and the phase delay from initially transmitted to received signals to differ for the two polarizations: That is:

$$\frac{|E_{REC(H)}|^2}{|E_{REC(V)}|^2} \neq 1 \qquad (r_\eta \neq r_v)$$

A brief experimental investigation was carried out to check these conclusions. A 200 Mc groundplane range was simulated on the CAL K_a-band CW cross section range, using a plywood sheet for the groundplane in one test and a metallic sheet for this plane in another. A 7/16" sphere was used as a target, and right circularly polarized transmission was employed, with both right- and left-polarized reception.

In a free-space range with this equipment, the ratio of signal power for left- and right-hand polarization was 35 db (the greater this ratio is, the more precisely true circular polarization has been achieved).

The results for the plywood sheet simulation are shown in Figure 1. The signal return power in db is plotted as a function of target height above the simulated groundplane, for each polarization of reception. Difference between the curves thus indicates ratio of left- to right-hand received power. The maximum value of the left- to right-hand signal-power ratio was 24 db, and this held over a very narrow range of target height, suggesting the need for more careful adjustment in height than may be possible with a large model. The maximum ratio occurred at a local minimum of the desired left-hand polarized return. At the first maximum of the desired return, the rejection of unwanted energy was only 15 db.

The metal plane did not do so well, as indicated in Figure 2. The maximum ratio was 12 db.

Clearly, the polarization properties of the antenna system were significantly altered by either groundplane, and were differently affected by the metal plane than by the dielectric one.

It has been suggested that if the dielectric is a uniform low loss material, then the phase difference between the reflection coefficients of the two polarizations can be ignored, and antenna gains adjusted differently for the two polarizations. Thus, it might be possible to change gains to effect a proper match. The gain requirement merely has to be:

$$\frac{g^2(\theta)_\eta}{g^2(\theta)_v} = \frac{(1+r_v)^2}{(1+r_\eta)^2}$$

This direct approach does not recognize two other perturbing parameters. They are:

(1) Nonuniformity of the dielectric plane. If the material constituting the plane is low loss material, then interior variations of dielectric constant can produce radical differences in the reflection properties of the two polarizations. Recent calculations have shown as much as 180 degrees of phase shift to be introduced by discontinuities in the dielectric material. This may prove particularly bothersome at the lower frequencies, where penetration of the refracted wave is measured in meters.

(2) High bistatic lobes produced by the target. Bistatic lobes from the target can illuminate the groundplane with a higher intensity signal than that backscattered directly to the receiving antenna. It can readily be seen that compensation of antennas would have to differ from the isotropic case and would have to be tailored to the particular target object, since

$$(1+\eta r_v)^2 \neq (1+\eta r_\eta)^2 \qquad \text{for} \quad \eta \neq 1,0$$

$$\text{and} \quad \frac{(1+r_\eta)^2}{(1+r_v)^2} = \frac{g(\theta)_v^2}{g(\theta^2)_\eta^2}$$

with η the ratio of bistatic return to direct return. This effect will be noticed primarily at the higher frequencies.

While the groundplane range has proven suitable for antenna measurements of linear antennas at the higher frequencies (S band and above), enough evidence exists to place development of precision cross section range in the experimental category. This is particularly true at the lower frequencies, and where polarization effects are to be measured with accuracy.

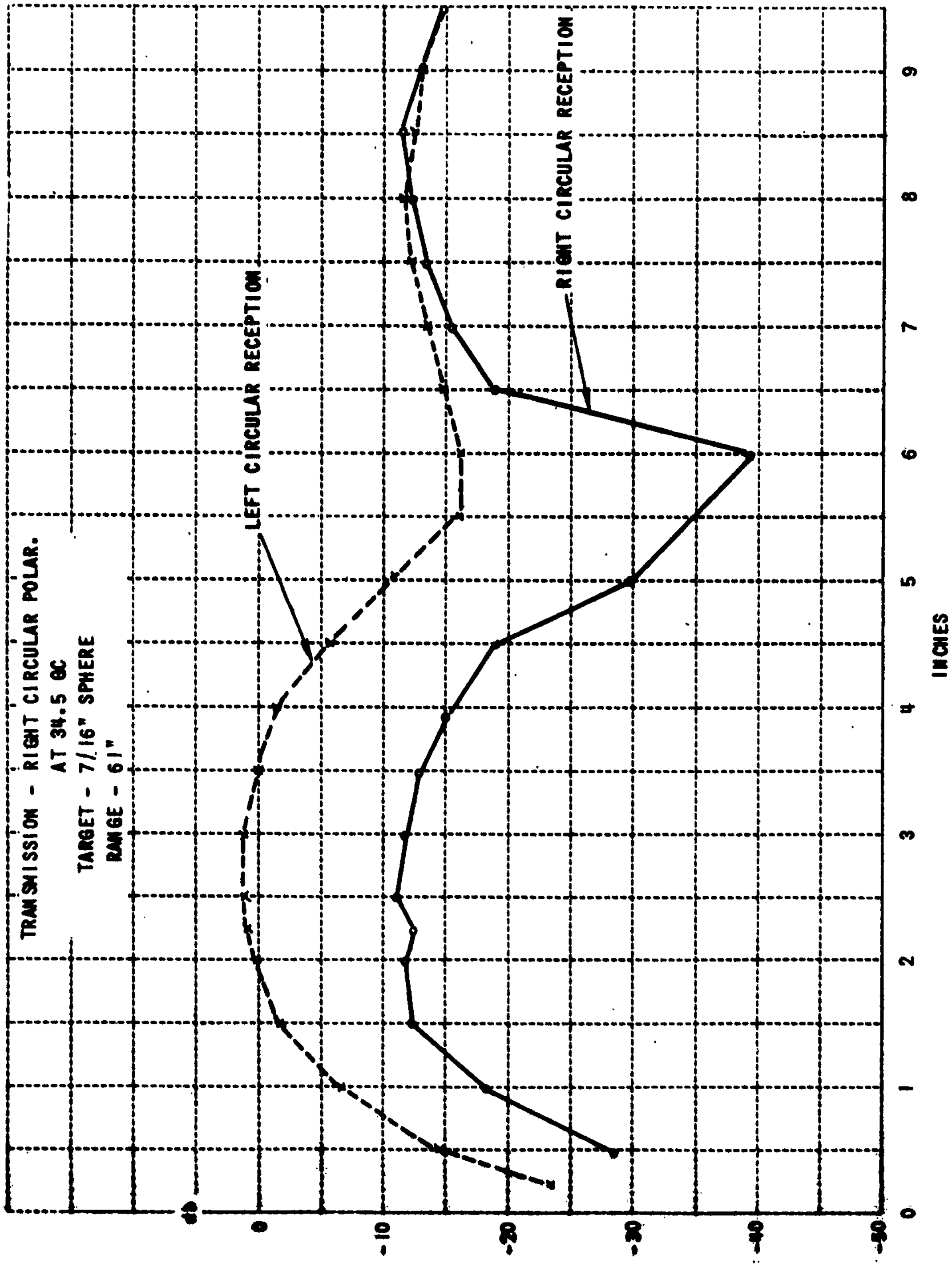

Figure 1 SPHERE HEIGHT ABOVE DIELECTRIC GROUND PLANE

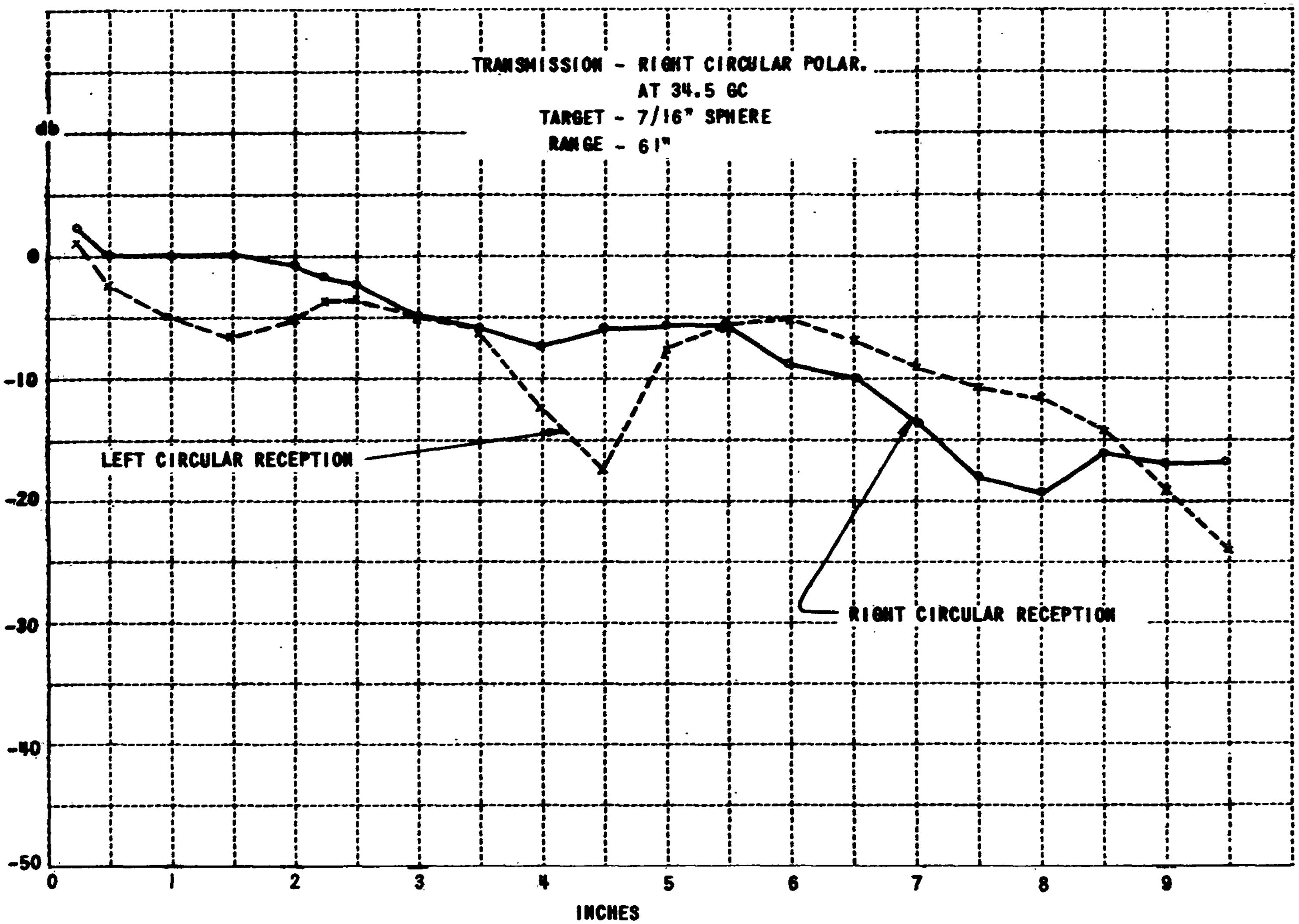

Figure 2 SPHERE HEIGHT ABOVE CONDUCTING GROUND PLANE